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PROBLEMS ENCOUNTERED IN IMPLEMENTING
DESIGN TO A COST IN MAJOR AIR FORCE
WEAPON SYSTEM ACQUISITION PROGRAMS

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Increasing pressure to reduce defense spending has encouraged new approaches to managing weapon system acquisition and ownership costs. The design to a cost concept is one of the newest approaches to cost reduction in DoD. Design to a cost is the process of controlling cost by treating an established cost target as a parameter of equal importance with system performance.

The SCAD program attempted to incorporate design to a cost in its full scale development contracts through the changes clause but found the cost prohibitive. Since the contracts had been signed, the SPO was negotiating with sole-source suppliers.

The A-X program implemented design to a cost in the competitive prototype phase. The target cost was set at \$1.4 million unit production flyaway cost. The Fairchild-Republic A-10 was selected as the winning design. The contractors design to a cost program met the cost target and encountered minor problems in its operation.

The AMST is a prototype program with a design to a cost target of \$5 million unit production flyaway cost. McDonnell-Douglas and Boeing are in the design phase with their individual proposals. Both contractors are operating within budget constraints but are vigorously pursuing the design target cost. Some problems in communication of the priority to be given to cost had to be overcome, but serious problems in operating with design to a cost have not been encountered by either AMST contractor.

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Problems which have been identified as being caused by design to a cost fall in the categories of communication, culture, operation and applicability.

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**PROBLEMS ENCOUNTERED IN IMPLEMENTING DESIGN TO A
COST IN MAJOR AIR FORCE WEAPON SYSTEM
ACQUISITION PROGRAMS**

THESIS

**Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology**

Air University

**In Partial Fulfillment of the
Requirements for the Degree of**

Master of Science

by

Stephen A. Hamer, B.S.

Major USAF

Graduate Systems Management

October 1973

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PREFACE

This report is the result of my attempt to find out what design to a cost is and what happens when the concept is imposed on a system development program. I was interested in what the real world problems were in using design to a cost for a major weapon system. I am indebted to Lt. Col. Robert J. Lucas, head of the Systems Management Department, for helping me to bound my curiosity and discipline my thinking. I might otherwise attempted a research project which could extend outside the limits of good judgment.

The list of those others to whom I owe thanks is long. Mr. C. Adams, A-10 SPO, Mr. W. Bogner, AMST program office, and Capt. Yost, formerly with the SCAD SPO were those at Wright-Patterson AFB who were particularly generous with their time and knowledge. The contractor program offices were most patient and helpful in providing the benefit of their knowledge to one--me--who manifested such naive ignorance of the complexity of the problem. The following were especially kind and generous to me: at Fairchild-Republic, Mr. V. Tizio and Mr. S. Granowetter, at McDonnell-Douglas, Mr. E. Dubil and particularly Mr. W. Johnson, and at Boeing, Mr. J. Peaslee along with many others. At each location I visited there were many who provided assistance and whose help I hereby acknowledge.

While I give thanks to others for the information received, I must accept full responsibility for its presentation and interpretation in this report. If there are any errors or mistakes they are mine.

STEPHEN A. HAMER

TABLE OF CONTENTS

	PAGE
PREFACE	ii
ABSTRACT	vi
I. INTRODUCTION	1
Background	2
II. RESEARCH OBJECTIVES AND METHODOLOGY	12
Objectives	12
Methodology	16
Definitions	17
III. DEFINITION OF DESIGN TO A COST	19
Title Given to the Concept	19
Defining the Concept	20
IV. SCAD	29
V. A-10	37
Air Force Issues	38
Contractor Issues.	41
Air Force Issues in Program Direction.	49
VI. AMST	56
General.	56
Air Force Issues	57
Contractor Issues at Douglas	67
Contractor Issues at Boeing.	73
VII. CONCLUSIONS	81
Communication	81
Culture	82
Operation	84
Applicability.	86
Recommended Areas for Further Study	88

TABLE OF CONTENTS (Cont'd)

	PAGE
VIII. SUMMARY.	90
BIBLIOGRAPHY.	94
VITA	96

ABSTRACT

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The AMST is a prototype program with a design to a cost target of \$5 million unit production flyaway cost. McDonnell-Douglas and Boeing are in the design phase with their individual proposals. Both contractors are operating within budget constraints but are vigorously pursuing the design target cost. Some problems in communication of the priority to be given to cost had to be overcome, but serious

problems in operating with design to a cost have not been encountered by either AMST contractor.

Problems which have been identified as being caused by design to a cost fall in the categories of communication, culture, operation and applicability.

I. INTRODUCTION

Over the past several years increasing public and official awareness of the cost of modern weapons together with a feeling of reduced immediacy of any military threat has focused greater attention and concern on weapon systems procurement. The spotlight on cost overruns and performance underruns bedeviled the development and acquisition of the Air Force F-111 and C-5 aircraft and many other defense systems in the mid-1960's. Some of the ideas and practices of the mid-1960's have been replaced by newer concepts and policies and shifted emphases in attempts to manage Department of Defense (DoD) purchases of major weapon systems.

Design to a cost is one of the concepts to have evolved during the past five years and is being applied more and more widely to acquisition programs. The annual Defense Department Report 1974 of Secretary of Defense Elliott L. Richardson, released on 10 April 1973, states, "We are exploring the feasibility of applying the design-to-a-cost concept to all major weapons systems," (12:18). The forces bringing about changes such as design to a cost within DoD have been complex and interwoven, difficult to identify and describe in detail on an individual basis. Nevertheless, design to a cost, while perhaps not formally titled so, has been common industrial and business practice for many years. Its application in the purchase of weapons in DoD is much more recent.

BACKGROUND

The public and political atmosphere of the late 1960's and early 1970's has been increasingly probing with regard to weapon systems acquisitions and the money involved. Congressional and public opinion have subjected DoD procurements to the spectrum from polite inquisitiveness to the harshest investigation and criticism. Congressional criticism was expressed by the Subcommittee on Economy in Government in May of 1969:

The total effect of unnecessary cost overruns, of hidden profits in 'fat' contracts, of inefficiency and waste, and the absence of cost controls is to create a bloated defense budget... there is evidence that literally billions of dollars are being wasted in defense spending each year. (11:4)

While this quote contains such emotional language as "hidden profits" and "fat contracts", there can be no doubt that real concern for the recent management practices of defense spending is evidenced by the subcommittee statement.

During the past several years competition for federal funds for a variety of housing, welfare, educational, social action, ecological, economic opportunity, etc., type programs has increased the pressure to reduce defense spending. The end of direct American military involvement in the Viet Nam war has added to that pressure.

Externally, critics of the Defense Department are demanding that the Defense budget be reduced by applying the "peace dividend" to nondefense areas. (9:1)

The international political atmosphere has also contributed to a growing, countrywide disinclination to continue spending large sums of money for major weapon systems. There seems to be a feeling of consciously placing faith and trust in the growing essential goodness of man evidenced by recent actions and international disarmament agreements. Bellicose competitiveness appears to be giving way to cooperative competition among the nuclear superpowers of the world thus, perhaps, reducing the need for newer weapons. A recent newspaper editorial gives evidence that the United States Senate is experiencing some such feeling:

...the Senate holds that because of the changing U.S.-Soviet relationship, this country at last can afford to forego much of the massive cost of a full, up-to-date defense. (15:2C)

This spirit of dentente-ism practiced by the faithful or hopeful, whichever the case may be, can provide a relaxation of tensions and reduction of fears among the population leading to lower commitment to defense spending. The previous editorial goes on:

The administration is basically right, but its position would be stronger by far if, first, the White House were laboring to cut out unnecessary military overhead and if, second, the administration weren't misapplying its own policy by proposing some highly expensive weapons that either are pointlessly redundant or frivolously innovative. (15:2C)

The dilemma before DoD places on the one horn the reduced fears of the population and on the other horn the continued insistence on force modernization by the military

services. The conflict can be expressed as the needs perceived by a war-weary population versus the needs perceived by professional military advisors.

In military terms the need for an operational capability is derived from an assessment of the potential enemy threat at the present and for the foreseeable future. An operational capability is possessed by a force composed of weapon systems, and when buying a specific defense system, constant attention must be paid to:

...what the minimum capability of the system must be. And these minimum performance numbers, gentlemen, are set by the enemy.
(14:10)

The Strategic Arms Limitations Talks (SALT) agreements either reached or believed possible have contributed to a no war threat view by the American people, putting further downward pressure on defense spending. However, a military assessment of the threat posed by a potential aggressor, the Soviet Union, indicated the need for continued spending to maintain and modernize our forces:

The central and imperative need,...is to maintain the deterrent capability of US strategic forces. "This means not only the maintenance of existing forces, but, more importantly, their modernization to preserve their survivability and penetration potential against an increasing aggressor capability."
(18:57)

The military claim of increasing aggressor capability could be regarded by the cynic as a scare tactic employed to maintain higher than necessary levels of defense spending. However, non-military sources provide support for the

military position. For example, the credibility of the aggressor naval capability is heightened by a recent claim that the editor of the 1973-1974 edition of Jane's Fighting Ships, considered the most authoritative annual on the navies of the world, considered the Soviet navy the most powerful in the world.

The United States possesses vast, though expensive, technological capability to produce civilian and military-related goods. American engineers have given us everything from a sub-compact car in a dealer showroom to a Moon Rover in a Lunar Excursion Module, as well as all the technology in between. But the technological capability presently possessed is not necessarily sufficient. The Soviet Union spends about half again as much as the United States in military research and development effort.

"...we estimate that with present trends, the Soviet Union will surpass us in terms of total defense-oriented technological capability somewhere between 1975 and 1978." (18:57)

Apparently there is a need for continued defense capability of a high order.

Thus the domestic attitude and the international situation seem to be forcing opinions to opposing views. The growing sentiment toward reduced spending is opposed by the conservative sentiment toward a continuing increase in military capability. The overall problem for the country becomes one of getting as much as the country can of what it would like to buy, constrained by what it can afford to buy.

Concerning the defense share of the federal budget, what the country can afford to buy, a preliminary study was done in the office of the Principal Deputy Director of Defense Research and Engineering (DDR&D), M. Leonard Sullivan, Jr. Mr. Sullivan said in an address in August, 1972, that the unofficial estimates of the future project a \$2 trillion gross national product by 1980. The historic rate of nondefense spending growth is projected to reach about \$400 billion a year by 1980. These figures represent only an estimate, but they do represent a best guess by DDR&E in 1972 on the availability of future funds for DoD. In explaining the projected figures Mr. Sullivan said:

As far as we can determine, the total estimated dollar increases between FY 73 and FY 80 will be consumed by anticipated inflation. In other words, we believe a \$112 billion budget in 1980 will be identical in purchasing power to an \$83 billion budget now. (16:2)

This "flat-rated budget" was subdivided into various categories and components in order to demonstrate the projected squeeze on funds available for investment in procurement, R&D, and other items. Although many simplifying assumptions were made in the analysis, the magnitude of the discrepancy between, for example, a \$4.2 billion "required" and a \$2.4 billion "affordable" annual funding rate for tactical aircraft indicates an out of balance situation which can not be ignored.

In summary, we believe there is no way to reallocate resources within forseen budget limitations to match the currently planned force levels with currently planned equipment costs and retain technological superiority

in all of our forces at the same time. We are driven to this conclusion largely because the unit costs of available options are, in many cases, substantially above the amount we can afford to pay.... (16:5)

In February, 1973, Dr. John S. Foster, Jr., OSD/DDR&E, was quoted by Air Force Magazine as stating the overall problem in these terms:

We must reduce the cost of acquiring weapon systems by thirty percent, or about \$7 billion a year, and we must do it without sacrificing technical excellence and without compromising the performance capabilities needed for military missions. (18:58)

The dilemma faced by DoD and the military departments did not, of course, appear suddenly but it has been growing more acute as the cost of new, sophisticated weapons has increased at a rate of five times that of inflation. This rapidly accelerating cost growth has caused DoD to generate methods for trying to effectively control the cost of new weapons. The design to a cost concept is currently the most common, new approach being used by DoD to control cost of new weapons.

Although mid-1973 finds design to a cost a common topic in reports and in articles written for defense-related periodicals and journals, there is not much to be found on the subject dated earlier than the 1970's. One of the earliest public references to the concept of raising cost to a much higher level of priority was made by Dr. Foster in an address to the National Security Industrial Association on 12 March 1970.

We shall insist relentlessly--as a point without peer in our management--that price has as much priority as performance. This does not rule out vigorous pursuit of new technology where that technology is required or can pay its way. And frequently, new technology can be used to reduce costs. Yet we must design-to-a-price, a much lower price, or else we will not be able to afford what we need. Defense budgets are going down. The costs of what we need, just our essential needs, are going up. Our only solution is to make cost a principal design parameter. That is how we must now define what is "best". We have no other choice. (9:4)

The Request For Proposal (RFP) for the A-X prototype competition was released in May 1970, shortly after Dr. Foster's speech, with a design to a cost target incorporated in it. The March speech by Dr. Foster also sparked a study on "Design to a Price" by the NSIA Research and Engineering Advisory Committee, a study that took two years to complete. The 1970 Defense Science Board Summer Study on Weapon-System Simplification, made under the auspices of DDR&E, made the following recommendation on the conduct of the requirements process. While it is not as specific proclamation on the design to a cost philosophy, the growing emphasis on cost is evident in the recommendation:

Establish an effective mechanism for treating major defense requirements at the Secretary of Defense level through a series of iterations of cost versus alternative solutions that begin with establishment of life-cycle cost thresholds against the capability sought and progress to definitize weapon-system development programs against specific cost goals. (2:1)

During 1970-71 the Army and Navy began using a "Should Cost" concept and the Air Force was evaluating PIECOST

(Probability of Incurring Estimated COST). Both were attempts to establish meaningful cost control systems at the outset of each weapon system procurement. Although Should Cost and PIECOST are attempts to integrate functional specialties in evaluating contractor proposals, they were also steps in the direction of the concept of designing to a cost target.

The formal statement of the requirement to design to a cost came in DoD Directive 5000.1, issued in July 1971. This directive established policy for major defense systems acquisitions. Paragraph III. C. 2. states in part:

Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into "design to" requirements. System development shall be continuously evaluated against these requirements with the same rigor as that applied to technical requirements. Practical tradeoffs shall be made between system capability, cost and schedule. (3:4)

In September, 1971, Mr. Doyle T. Brooks, Jr., of Vought Aeronautics Company presented a paper to the National Aeronautic and Space Engineering Meeting of the Society of Automotive Engineers on controlling costs in the design stage. He noted that the producibility of a product is largely determined during the design stage and can be measured in terms of cost. The paper, titled, "Designing for Producibility: Design-Influenced Production Cost Program", presented a plan for tracking and controlling the

end-product costs by creating cost targets at the beginning of the design phase.

A symposium on "DoD Procurement in the 70's" was held at Wright-Patterson AFB, Ohio, in February, 1972, and Mr. Raymond D. Gilbert of the DoD Value Engineering Service Office presented a paper on "Designing for Cost to Produce". Mr. Gilbert compared the development of a new weapon system to the development of a commercial product. He summarized by saying:

The concept of controlling cost-to-produce while a product is being developed is supported with adequate industrial management disciplines which are within the public body-of-knowledge.
(5:60)

Further DoD efforts in 1972 included a preliminary study addressed to what the design target cost should be conducted by the office of the Principal Deputy DDR&E. Also DoD proposed a draft handbook on "Cost-to-Produce", and speeches on the subject were made by several high Defense officials before meetings of defense-related industry associations. The Joint Logistics Commanders' (AMC/NMC/AFLC/AFSC) Panel on Design to Unit Production Cost Goals was given the task of examining industry and government procedures for tracking unit production cost goals. The Air Force Systems Command Technical Management Council Meeting in September was devoted to the design to a cost concept for weapon systems.

Current literature on design to a cost is somewhat limited and contains varied interpretations of some version of

of the term. Attempts at definition are not wholly successful and lack generality. Differences of opinion concerning meaning and applicability are evident, and there are no uniform practices extant on the employment of the design to a cost concept in major weapon system programs. Moreover, there is nothing currently documented concerning actual problems that have been encountered in implementing the concept in a major defense acquisition program.

By mid-1973 there was a growing body of operational experience in both industry and the Air Force on the usability and the limitations of the design to a cost concept in such major programs as the SCAD, A-10, AMST, lightweight fighter prototype, and some B-1 subsystems. With such a diversity of applications a reasonable assumption could be made that problems in implementing a new concept had been encountered and an examination of one or more of the major programs could bring some of these problems on design to a cost to the attention of users and potential users alike.

II. RESEARCH OBJECTIVES AND METHODOLOGY

OBJECTIVES

The primary objective of this study is to examine some current examples of design to a cost in the airframe segment of the aerospace industry to learn what problems the application of the concept generated. In other words, what problems in the acquisition of a major weapon system are peculiar to the concept and might be modified in applying design to a cost.

In a paper prepared for presentation at the U.S. Naval Academy Mr. James D. McCullough lists some steps which he considers that DoD undertakes in a design to a cost procurement procedure:

1. Define military requirement.
2. Decide that requirements can be met by "Design to Cost" procedure.
3. Establish "Design to Cost" target and functional specifications.
4. Issue RFP for Development Contracts (Competitive Prototype Development).
5. Evaluate industry proposals.
6. Award competitive contracts for prototype development.
7. Monitor prototype contracts.
8. Conduct prototype "flyoffs". Evaluate performance and potential production costs.
- *
9. Award Fixed Price Production Contract with warranties for reliability and maintainability.
10. Monitor production contract and system operation...
- * Steps not listed include completing full scale development, including OT&E of the complete weapon system, and obtaining DSARC III approval for production. (10:13)

The list is general, but it is used here to establish the context in which this study was undertaken.

In order to complete the first of Mr. McCullough's steps, and in order to avoid dealing with such philosophical and political issues as national goals and policies, roles and missions of the various military services, etc., requirement is taken as given. Since most of the programs examined in this study are officially designated as design to a cost programs by DDR&E the second step has already been taken.

The establishment of the design target cost, the third step in Mr. McCullough's list, involves such areas as the military requirement, force structure planning, economic projections, and budget expectations as well as national strategy. For this reason it is believed that there is sufficient room for several studies in looking at the process of establishing this parameter alone. For this study, therefore, the starting point follows the time when the cost target and the weapon system performance have been established.

This study was originally intended to examine the implementation of the design to a cost concept in one major USAF acquisition, the Subsonic Cruise Armed Decoy (SCAD). This program was divided into segments managed by separate program managers, and the System Program Office (SPO) was responsible for the integration of the five segment contracts awarded to four contractors. In choosing the SCAD the major consideration was the availability of one single, convenient location

for five separate design to a cost efforts by four unrelated contractors. The SCAD was a major weapon system acquisition program offering both high cost and low cost, high technology and low technology segments for examination. In addition, there was an opportunity to study the integrated and major design to a cost effort on the total system.

Very early in the study it became apparent that additional data would have to be sought from other programs. The reasons for this change are detailed in Chapter IV. Support for this expanded study was then sought in the System Program Offices for the A-10 (formerly A-X) and the Advanced Medium STOL Transport (AMST). These programs have been officially identified as design to a cost efforts by DoD as of April, 1973.

One of the limitations of this study is the point of departure for examining design to a cost implementation problems. The arbitrary decision to begin at the point where the target cost and performance goals had been established excluded from the study many important, perhaps even more important, problem areas such as the whole requirements process and how to establish a target cost to design to. Still the problems encountered in managing a program with design to a cost constraints were thought to provide a fruitful area for study. The SPO is less concerned with the source and justification for program objectives than it is for managing to them.

The acquisition cycle proceeds through conceptual, validation, full scale development, production and deployment phases, and cost control in major systems acquisition must obviously be concerned with all phases. The design to a cost effort must necessarily continue through the acquisition cycle to derive maximum system capability while still remaining within the cost target. However, the major impact of design to a cost is likely to be realized in the early phases. The design to a cost concept applied in the conceptual and validation phases has the greatest influence on system cost for once the design is frozen there is limited cost reduction available thereafter.

This study assumes that there have been and continue to be problems caused by implementing design to a cost in major weapon systems acquisitions. The SCAD, A-X and AMST were chosen for this study because they appear to be representative of major USAF weapon system programs with regard to design to a cost implementation.

The first task of this study is to find out what design to a cost is in actual practice. There is an operational concept of design to a cost which can be defined effectively to provide for common understanding and to facilitate communication. The second task is to learn what specific problems can be directly attributed to the use of this concept. Guidance for the future implementation of design to a cost will be inferred where possible from the analysis of specific problems.

The examination in this study of design to a cost applications is made to identify and isolate those problems generated by implementing the design to a cost concept. There is no intent that this study make any judgment as to the merits of the design to a cost concept, and no attempt is made to assess how well or how poorly the concept has been implemented or not implemented in specific programs.

METHODOLOGY

A literature search was employed to gather information and background on the circumstances which led to the application of design to a cost and on the meaning and scope of the concept as perceived by the DoD and aerospace officials represented.

The case study method was used to gather primary source data at Wright-Patterson AFB and contractor facilities. The initial research was done at the SCAD and A-10 SPO's and at the AMST office of the Prototype Program Office. Documents and individual interviews were the primary data sources. Requests For Proposal, internal memoranda, letters, excerpts from the Bidders' Briefings for the A-X and AMST, etc., were some of the documents which gave insight into the general practices and the Air Force intent of the design to a cost programs. The interviews were held with procurement and production specialists and financial or business managers. Initially the interviews were somewhat directive in that the intent of the study and the types of information

needed had to be established. Subsequently, interviews became much less constrained and structured because the information forthcoming became wider ranging and narrative. Care was taken to avoid pointing interviews toward only certain predecided problem areas.

Field research was completed with one-day visits to the three contractor facilities involved in the A-10 and AMST programs. Extensive discussions were held with program executives at Fairchild-Republic at Farmingdale, N.Y., Douglas Aircraft Division of McDonnell-Douglas Corp., Long Beach, Ca., and the Aircraft and Information Division of the Boeing Co., Seattle, Wa. The discussions with the contractor representatives were guided only in the general area of the design to a cost problems in order to avoid limiting the interviews to a discussion of certain specific problems.

DEFINITIONS

The establishment of some particular cost as a target must be accompanied by a specific definition of exactly which cost is to be used. There are some specialized cost definitions employed by the Air Force in weapon system procurement which do provide standard and common bases for whichever costs are to be used. The following definitions are taken from the "Instructions for Preparation of AF Forms 1537 & 1539 (Missile and Space Systems Production Costs)". These are standardized definitions used in the SCAD, A-X and AMST programs.

Recurring Flyaway Cost. Summarized subsystem cost estimates of airframe, propulsion, electronics, armament, other GFAR/CFE and ECO of a recurring nature which represent complete space/missile system. ("Over-the-fence")

Other Recurring. Effort of a recurring nature not included in subsystem costs of the Air Vehicle Equipment...

Nonrecurring Cost. The initial set of tools and duplicate tools produced to obtain a specific rate of production, and other effort not included in above category of costs.

Flyaway Costs. The sum of recurring flyaway, other recurring flyaway and non-recurring costs.

Peculiar Support Costs. The sum of costs for peculiar Ground Support Equipment (usually identified as Aerospace Ground Equipment (AGE), Peculiar Training Equipment, Publications and Tech Data and Site Activation effort.

Weapon System Cost (Gross). The sum of flyaway and peculiar support.

(6:1)

III. DEFINITION OF DESIGN TO A COST

TITLE GIVEN TO THE CONCEPT

In trying to define the concept it would be helpful to have a single name to use for it. Just as there is some uncertainty and some confusion as to the definition of exactly what design to a cost is there is also a variety of names to be found for the concept. Each name seems to be dependent upon the particular focus of the user. "Design-to-cost" appears most often in the literature, but this term seems to carry with it the connotation that cost is a complete idea. It seems to say that if a system is to be a "design-to-cost" effort then the design target has to include some sort of whole embodiment of all the costs, whatever they may be. Unfortunately, it appears that design-to-cost means all costs unless otherwise specified.

Design-to-price is the next most common term in use, and it does overcome the deficiency of the cost-only term. While the design-to-price name tries to embody the idea of what the Government pays for an item it, too, suffers from carrying a connotation of totality, the idea that if you design-to-price you include every dollar to be spent on the item or system. The discussion could be pursued to include other current terms, such as design to unit production cost goals, cost-to-produce, and several others. However, even the question of cost or price as the more nearly correct term appears somewhat academic. In simple terms the difference between cost and price could merely be the difference

between the viewpoint of buyer and seller. In the case of the buyer it will cost him so many units of value. In the case of the seller he will sell at a price of so many units of value.

In the broad view the language of DoDD 5000.1, "... discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into 'design-to requirements,'" indicates that any and all costs should be made the object of a design-to effort. Whether or not every system element should be so treated is somewhat outside the scope of this study, but the point is that any cost element could be made the object of a design-to effort. The intent of the directive is taken here to be to require design to a discrete cost without specifying the limits or level of aggregation to be used. It would seem, therefore, that the term, design to a cost, is the least limited term of description for the concept, carrying neither the connotation of a totality nor specifying to which cost the concept may be applied. The most recent speeches, articles and interviews with spokesmen from within DoD suggest favoring the general use of design to a cost. In the interest of clarity and consistency design to a cost will be used in this study.

DEFINING THE CONCEPT

While the choice among names may be made arbitrarily the synthesis of a correct and operational definition of

the concept is a problem of a larger magnitude. There are apparently as many definitions as there are proponents of the concept most of which agree in substance but vary in application. Most writings defined what design to a cost would mean in the context of the article or with the perspective of the author. Each definition was therefore narrowed from the general concept to the specific application.

Dr. Foster provided the early thrust of design-to thinking in the Forrestal address of March, 1970:

We shall insist...that price has as much priority as performance. ...we must design-to-a-price, a much lower price, or else we will not be able to afford what we need. Our only solution is to make cost a principal design parameter. (9:4)

The majority of definitions of this design-cost interrelationship are still being applied to the cost of producing a particular design. That is, the definition is provided in terms of an engineering concept limited in scope to the production of item A or system B.

In March, 1973, the Director of Procurement Policy at USAF headquarters distributed an analysis of the "Design-to-Price Concept", which defined the concept this way:

The Design-to-Price Concept is the embodiment of a systems/equipment acquisition approach which uses a unit production price established prior to or early in the development effort as a design and cost constraint. (4:1)

Others have related cost to the government rather than price by specifying unit production cost for an item or system as the definitive element.

Adopting a slightly different approach the following author uses a certain kind of cost with a high priority:

The Air Force Avionics Laboratory at Wright-Patterson...is orienting more and more of its advanced development projects to balanced designs, considering cost of ownership equally with performance. (13:59)

The article goes on to explain that cost of ownership is all the costs involved in investment and deployment of a subsystem.

Each of the above definitions was sufficient for the limited purposes of the author and served the purpose of a conceptual framework for the article. But none of them serves to define design to a cost as a framework broad enough to be generally applicable. Design to unit production price, design to unit production cost, design to cost of ownership are all examples of the application of design to a cost, and each one is a subset of the set of all possible design to a cost elements.

It might be well to consider at this point, in a very simple fashion, what occurs during the design cycle. The design cycle basically begins with what is to be done and how much in resources can be devoted to the requirement. The job that needs to be done is translated into design goals or requirements; the company finds out what talent and technology is available; and a design is created. The proposed design is evaluated against the design goals, and the design is evaluated for the resources it will require. When costs are excessive several design iterations may be

necessary to bring the cost of the design to within the resources available. Any parameter can presumably be made very important, and any kind of cost can be made the very important parameter during the design cycle.

Mr. Leonard Sullivan, Jr., DDPA&E (formerly Principal Deputy DDR&E), writing for the Defense Management Journal for July, 1973, explained that the driving force behind the design to a cost concept is the objective of assuring the affordability of new systems required by DoD. He then described how design to a cost should work:

By deciding approximately how much we can afford to spend on a particular mission area and its systems and then designing to that target cost, we hope to control our acquisition and ownership costs, thus assuring that the most capability is derived from our resources. (17:2)

Mr. Sullivan has described the process of designing to a cost; the process undergone in all the individual applications of designing to some cost. It would appear that a rewording of Mr. Sullivan's thoughts could provide a sufficiently general and accurate definition for design to a cost, namely:

Design to a cost is the process of controlling acquisition and ownership costs by treating an established target cost as a design parameter of equal importance with system performance.

Some of the advantages of such a definition are the lack of specifics regarding how to design, how to establish target costs, how system performance is to be expressed, and the mechanics of the cost-performance interaction. A big

disadvantage of such a definition is the restricting of the process to one of controlling acquisition and ownership costs.

Defining design to a cost as the process of controlling acquisition and ownership costs implies that all of these costs must be controlled by the process. However, design to a cost can be used to attempt to control acquisition or ownership costs by controlling elements of these costs. In the aerospace industry today less than half of the acquisition costs of an aircraft are controllable in design. More than half of the product costs are indirect and allocated overhead costs. The total cost of ownership of past systems can not be calculated because inadequate operational data were gathered, and, therefore, no adequate, predictive cost of ownership model is available. Although total cost of ownership contains unknown elements and elements unaffected by design, there are cost elements which might be controlled in design. To imply, however, that design to a cost can only be used to control the total acquisition or ownership cost through design actions would be misleading.

While the intent of Mr. Sullivan's definition is to inform as many potential users as possible, the implication is that one must necessarily be controlling cost of acquisition or ownership in order to design to a cost. It is questionable whether sufficient knowledge or business acumen exists at this time to be able to estimate the non-recurring or fixed costs to be allocated to a program. Such an estimate would have to be based on a prediction of the business base

a company may have at some known or unknown time period into the future. As to cost of ownership:

The shift from life-cycle costs to production costs is, no doubt, just a practical one which reflects such factors as our poor data collection systems for operating costs, the inadequacy of feedback mechanisms from the field to designers, and the lack of contractual procedures for enforcing operating cost specifications. (9:4)

If the two modifiers, acquisition and ownership, are simply removed from Mr. Sullivan's definition, design to a cost becomes the process of controlling costs, any specified costs, by treating cost as a primary design parameter. And that is not a bad definition to operate with. When applied to a specific program it may be sufficient guidance to accomplish the objectives for that program. It is not sufficient to define the concept with complete satisfaction. Any operating definition should have more than just advantages to be useful, it should apply the conceptual framework to the specific situation, to whatever real problem which has presented itself.

An operating definition of design to a cost should contain the elements of action, timing, purpose and constraint. The definition need not concern itself with success or failure, merely with the nature of the required effort. The action element of design to a cost is the taking of positive design actions and making design tradeoffs between cost and performance or schedule. These actions largely occur in the conceptual or validation phases when the effect of cost as a major design parameter is greatest. The process has the

purpose of causing the designing of an item or system with a specified minimum military capability. The constraint is the objective of designing the maximum military capability possible within the resources made available. The resources made available are expressed as an established target cost.

The target cost which is established for a program need not be a certain kind of target cost in order to qualify as a design to a cost parameter. It does need to be expressible in finite terms as a discrete cost category or relationship in order to be part of a viable effort. There seems no reason to say that a design to a cost effort must have a unit production cost target, or a life cycle cost target, just as long as the cost target is definable. DoD 5000.1 directs discrete costs as objectives in the design-to efforts giving unit production costs as one example, operating and support costs as another, and excluding no category from consideration. There are several examples of design to a cost programs which exhibit a variety of target costs. The A-X had a cost target expressed in dollars per unit recurring flyaway cost. The Gimbaled-Electrostatic-gyro Aircraft Navigation System (GEANS), a small Avionics Laboratory program, was managed to a dollars per unit cost of ownership target. Both programs are design to a cost. The difficulty with the cost target lies in selecting a cost which is susceptible to both reasonable estimation and

accurate tracking and which meets the general requirements of the program.

The following definition is proposed as a current and valid operating definition of design to a cost:

Design to a cost is the process of taking actions and making tradeoffs in the design phase which will keep the cost of the design from exceeding the established target cost while assuring that maximum capability is derived from available resources.

This definition has the same non-specificity advantages of some of the earlier examples given. Also this definition does not suffer from restricted applicability. It is an active and descriptive definition, though possibly an inelegant one.

It should be noted at this point what design to a cost is not. Design to a cost is not a system, for:

A system is "an organized or complex whole; an assemblage or combination of things or parts forming a complex or unitary whole."
(8:4)

First, there must be a purpose, or objective, which the system is designed to perform. Second, there must be design, or an established arrangement of the components. Finally, inputs of information, energy, and materials must be allocated according to plan. (8:113)

The established cost target is integrated into the control subsystem of a management system, but there is no established arrangement of the components of design to a cost. The design to a cost concept becomes part of a management philosophy for integrating resources into a system for objective accomplishment.

Design to a cost is not a procedure to be followed consisting of so many steps to be completed.

The procedure (or method) tells how to do the job, what processes to use, and other general information about the job. The procedure is task-oriented; it normally is written as a formal document segmenting the tasks to be performed. (8:116)

Giving a high priority to cost, establishing the target cost, and making design tradeoffs are elements of designing to a cost. But there is no formal instruction for operating with design to a cost.

Design to a cost as herein defined was not practiced in the weapon system acquisition program for the SCAD. Design to a cost is being practiced in the A-10 and AMST programs. The following chapters review in some detail the design to a cost implications in each of those three major acquisitions. Chapter IV covers the unsuccessful attempt by the SCAD SPO to implement design to a cost. Chapter V is a review of the A-X (A-10) program, which has the longest term design to a cost experience of the three studied. Chapter VI is concerned with the AMST. The AMST program is actually two separate design to a cost programs being operated by independent contractors in the prototype phase.

IV. SCAD

The Subsonic Cruise Armed Decoy is an air-launched guided missile whose purpose is to saturate, confuse, divide and attack enemy defenses and thus enhance the penetration ability of the U.S. strategic bomber force. Designed to be carried aboard a B-52 and launched prior to penetrating enemy early warning defenses, the SCAD had to look and behave like a B-52 when detected by enemy radar. The SCAD would thereby cause defensive capability to be committed against itself drawing fire away from the manned aircraft. If launched in an armed configuration the SCAD would possess an offensive as well as decoy capability.

The SCAD was a major Air Force weapon system acquisition program which, by mid-1972, had completed the validation phase of the system acquisition life cycle. While awaiting ratification by the Defense Systems Acquisition Review Council (DSARC) and Development Concept Paper (DCP) approval by the Secretary of Defense, authority was granted by DoD to proceed with awards for full scale development subject to review and possible redirection in the future.

The SCAD program was subdivided into five separate segments for management of the design and development work of separate contractors. There was a separate contract and Air Force segment project director for the SCAD airframe, engine, navigation-guidance, decoy and carrier aircraft equipment segments. The responsibility for system integration was retained by the SPO and was managed as a segment

separate and equal to the other five. Each segment project director was a program manager for his segment similar to what the System Program Director (SPD) was on a larger scale.

The SCAD SPO was basically organized in a conventional manner but with the addition of a Projects Division under the SPD of equal status with the six divisions found in the typical SPO organization. Just as the SPO is the focal point between the Air Force and industry for the direction of the system contract, the Projects Division is the focal point between the SPO and the contractor for the direction of each segment contract. By July, 1972, contracts had been awarded to each segment contractor for full scale development of the SCAD.

The August, 1972, speeches by Dr. Foster, DDR&E, and his (at that time) Principal Deputy, Mr. Sullivan, before the National Security Industrial Association generated wide publicity to the idea of designing to a cost. Through the initiative of the Chief of Procurement and Production a decision was made by the SCAD Program Director to establish a design to a cost program for the SCAD Program to use as an internal management tool.

In order to understand and employ the design to a cost concept the SPO sought assistance for themselves and their contractors from Air Force Systems Command, the Air Staff, and DoD. The Product Engineering Services Office at DoD sent Mr. R. L. Bidwell and Mr. R. D. Gilbert to assist the

SPO in the planning for design to a cost on the SCAD. The February, 1972, presentation at the Wright-Patterson AFB procurement symposium had established these two men as among the most knowledgeable on designing to a cost.

In the RFP's released for the full scale development potential contractors were advised that the overall objective was to accomplish program development at minimum cost (unspecified) consistent with achieving program objectives. The development contracts were structured with incentives on cost, but the RFP's and the negotiated contracts did not contain design to a cost parameters. The addition of design to a cost parameters would be a change to the terms and conditions of the existing contract, and in each case the individual segment contractor would be in the negotiating position of a sole-source supplier.

In October, 1972, Advance Change/Study Notices (ACSN's) were released to the contractors for each of the five segments requesting their evaluation of the additional cost of contracting for design to a cost. In November the contractors responded to the ACSN's stating that if a full design to a cost implementation to include an established unit production cost goal was desired then the added cost for the SCAD development program would be \$5 million, a figure the SPO found unreasonable.

Negotiations were held with all segment contractors with the objective of implementing no-cost supplemental agreements reflecting only goals toward which the contractor

would agree to work with no contractual incentives or penalties. The resulting agreements provided for:

- 1) the recognition of a design to a cost goal for recurring production costs in each development contract,
- 2) the monthly review of the cost goal at Segment Status Review meetings,
- 3) the detailed analysis of the cost at key program milestones, and
- 4) amendment of the statement of work so that future engineering change proposals would include the net change in the cost goal which would result from the proposed change.

The net effect of the contract changes negotiated was to establish a production cost objective with a mechanism to review production costs during the development phase.

The SCAD contractors were reluctant to accept any kind of a design to a cost program which required them to perform or to report data without additional cost. The desire to participate on the full scale development contract could very easily bear on the subsequent award of a production contract. This was sufficient to motivate their acquiescence. In January, 1973, all segment contracts were modified under the authority of the changes clause to include a design to unit production cost gals. No contractual leverage was incorporated to enforce adherence to the cost goal, however.

Time and schedule pressures were important inhibitors of the effort to incorporate design to a cost in the SCAD program. The established schedule for the program constrained the SPO from implementing a completely new design to a cost concept subsequent to the award of contracts for the full scale development phase.

Disregarding the label applied to these contract changes the question might well be asked, Was this really a design to a cost effort? The essential elements of a design to a cost effort, taken from the operating definition synthesized in the previous chapter, are that actions be taken in the design phase, that these actions be taken to remain within an established cost target, and that they derive the maximum benefit from the available resources. All these elements appear to be present in the modified SCAD segment contracts. However, the established cost target is variable. Changes proposed and accepted can result in a revised target cost. Thus, some parameter other than cost can have the highest priority. Cost is something of a dependent variable regardless of the attention and visibility it gets.

A second difficulty in accepting the SCAD effort as representative of operating design to a cost concerns the phase in which the target cost goal was established. The Bidwell-Gilbert briefing on "Designing for Cost to Produce", which played a significant part in SCAD planning for their implementation of design to a cost, makes use of the Pareto distribution, the 80-20 rule. The Pareto distribution is

borrowed from the social sciences to help focus attention on the cost of the "significant few" as offering the best opportunity for cost reduction. In the paper the authors plot the cumulative percentage cost as a function of the percent of total items arranged from greatest to smallest. The point is then made that eighty percent of total cost can be attributed to the first twenty percent of total items. That is, the relationship exhibits the Pareto distribution. It is suggested that cumulative percent of total cost could be plotted as a percent of total design decisions made. These decisions arranged from greatest to smallest impact on the overall design would consequently show the greatest impact on overall cost.

The "significant few" decisions on size, configuration, range, etc., of the SCAD would account for the overwhelming majority of cost impact. The detail design of parts and components, producibility decisions, would be well out in the "insignificant many" and would account for much less cost impact. The implementation of design to a cost in the SCAD came after the "significant few" decisions had long since been made, and the detail design decisions being made in full scale engineering development were among the "insignificant many". The effort in the SCAD, therefore, might be more accurately described as value engineering with an established cost goal than design to a cost. Had the cost target been firm the program might have merited the

design to a cost label if the SPO were to take the remaining decisions in a program to design to a cost what is left to be designed.

In the SCAD program each project director was encouraged to solicit tradeoff proposals and thus seek cost savings in design changes he might find fruitful. The establishment of a unit production cost target for each segment, even though it was subject to change, resulted in increased cost consciousness and gave visibility to the cost impact of design changes.

In July, 1973, DoD ordered the Air Force to halt full engineering development of the SCAD. The program has been redirected to a study effort.

In summary, then, design to a cost was not implemented in the SCAD program. Although design to a cost can be most effective in early phases the concept could conceivably be employed at anytime. However, the concept depends for effect upon giving cost at least as high a priority in decision making as any other parameter. At the time the concept was introduced into the SCAD program the conceptual and validation phases had been completed and contracts had been signed for full scale development. The SCAD SPO was unable to establish a firm target cost and design to it because design to a cost had been introduced into a sole source procurement environment in which cost was not the primary parameter. The problem stemmed from having to deal

with contractors after contracts had been signed with maximum technical effort enjoying a higher priority than cost.

While the design to a cost concept might not have been successfully applied in the SCAD, the program derived some benefit from the belated attempt at application. The SPO was able to introduce cost targets as point of emphasis to serve as a focus for management effort. They also succeeded in having the net cost impact of changes made a part of the information required on Engineering Change Proposals (ECPs). Increased awareness of design-cost interrelationship was achieved.

V. A-10

A-X was the preliminary designation given to the weapon system to be acquired to satisfy an Air Force need for a specialized close air support aircraft. The requirements for this acquisition were, and still are, an effective weapon system for a specified operational mission which can be acquired and owned at a low cost. The procurement approach used was design to a cost, with competitive prototype to demonstrate the operational suitability and the producibility of alternative designs.

For the competitive prototype phase (CPP) solicitations were extended to eleven aerospace companies to compete for an opportunity to design, develop, fabricate, test and support two prototype aircraft. The CPP contract was a firm fixed price (FFP) contract with an incentive for successful performance to develop and produce a sizeable number of these aircraft. Two contractors were selected for the award of FFP contracts based primarily on the bases of costs of the proposed aircraft and the technical adequacy of the proposals. The competitive element present in the bidding was the production unit cost. The price of the prototype contract, provided that it was within reasonable limits, was not a significant factor in the selection of the two contractors. Air Force evaluation included an actual flyoff of the competing designs which provided a level of confidence in the military capability of the competing

systems. In addition prototyping provided a means of realistically estimating the production costs of the proposals.

The full scale development phase opened with the selection of the Fairchild-Republic Company of Fairchild Industries for the award of a cost plus incentive fee (CPIF) contract to build 10 pre-production aircraft on a negotiated schedule. The incentive is tied to cost alone with no incentive or penalty based on higher performance, maintainability, reliability, weight or schedule. The full scale development contract, a CPIF contract, has a fixed price, incentive fee option which the government can exercise to buy forty-eight production aircraft.

Government furnished equipment (GFE/GFAE) for the weapon system includes such things as avionics, armament, engines and some airframe items with the prime contractor responsible for integration. The costs of GFE/GFAE were provided to the contractor for use in his cost projections.

At the time of this writing no production contract is being negotiated. The only production being actively considered by the Air Force is the forty-eight plane option on the full scale development contract.

AIR FORCE ISSUES

In the first paragraph of the introduction to the A-X RFP for the CPP low cost was described as crucially important and second only to weapon system effectiveness. Obviously the Air Force was not going to buy an ineffective

weapon system just because the cost target had been met.

The definition of the cost target to which the offerors were to design was specified as:

...less than \$1.4 million per unit flyaway
(recurring costs - FY 70 dollars) for a
600 aircraft buy at a peak production rate
of 20 aircraft per month. (7:1)

It is interesting to note that the cost target follows immediately after this sentence:

"The acquisition and ten-year operational
and maintenance costs must be minimized;
otherwise approval to proceed into the
acquisition phase will be denied." (7:1)

Following the admonition of minimize ten-year ownership costs along with a unit flyaway cost points out an inadequacy of current cost estimating procedures and accuracy. There is no sufficiently accurate model for life cycle costing a major weapon system currently available. Without a model for accurately estimating life cycle costs there is no way to establish a firm and reasonable life cycle cost target to design to. The current state of the cost estimating art will permit only certain types of cost targets to be used with confidence in a contract.

The second part of the quoted sentence is the statement of the importance Air Force attached to the target cost. Target cost and the incentive of possible follow on production were directly, firmly and invariably tied together, and the offeror could not have the one without the other.

The target cost was subsequent changed to \$1.5 million unit flyaway cost. The new target merely added non-

recurring costs to the previous \$1.4 million target so that the final design to a cost target includes recurring and non-recurring unit flyaway costs for airframe, engines, avionics, armament, rate tooling and an allowance for engineering change orders.

The requirements specified in the RFP were stated as goals to be achieved if possible, not standards to be met at any expense. The performance goals, tailored to the intended use of the aircraft in the close air support role were established in the RFP for production aircraft. The contractors were given complete design latitude as to what kind of aircraft they would propose to meet those goals. The RFP made no requirement for MIL-SPEC or MIL-STD design or execution. Only safety standards were specified for the prototype aircraft.

The RFP for the CPP was really at the heart of the A-X design to a cost effort. It was in the formulation of the requirements stated in the RFP that the means was set for achieving an effective weapon system design at a target cost. The RFP was carefully scrubbed through several iterations in order to retain only those MIL-SPEC and MIL-STD requirements for the production aircraft which were considered by the SPD to be essential for this system. The requirements for the A-X were very carefully examined and closely controlled by the SPO to prevent the proliferation of the "ilities" requirements and gold plating which have often attended increasing system costs in the past.

CONTRACTOR ISSUES

Fairchild-Republic Company of Farmingdale, N.Y., had been sustained since the final F-105 rolled out of the plant by subcontract work on a variety of military and commercial aerospace systems. The company still retained a core of experienced employees and had, from time to time, responded with proposals on a variety of aircraft and systems. The motivation for Fairchild-Republic to respond to the A-X RFP was basically that of an aerospace company with excess capacity, related experience, and an interest in returning to the position of prime contractor on a major weapon system.

Company capability included the availability of design engineers and all the other specialties needed to form a project team. Production possibility was the strongest of incentives to compete even though the company had no design to a cost experience. The company had used the producibility team concept for over fifteen years in value engineering efforts. The Management Information and Control System was modern and up to date, and cost visibility and tracking expertise was being currently exercised. Manufacturing space was abundant and numerically controlled machinery permitted imaginative tooling, fabrication and assembly techniques.

When the RFP was released there was some uncertainty as to the importance of the cost target. The Bidders'

Briefing and subsequent interaction with the SPO erased this uncertainty from the mind of the contractor's program director and he became committed to the design to a cost concept. In his own words, "Once I was sure the SPO was serious about cost there was no other way to go." The Deputy Chief of the AFPRO at the Farmingdale facility calls the design to a cost effort underway at Fairchild-Republic successful, and he credits the conviction of the contractor program director in the value of the design to a cost concept for the success achieved. The Air Force did not fail to communicate the importance or the priority of cost to the contractor.

The program director felt that the attitude of the SPO was a most important factor. He felt that the SPO spoke and acted with the firm conviction that cost was crucial to the system. The SPO restrained themselves from becoming engaged in forcing design factors into the company design effort. Combat mission requirements concerning, for example, the cockpit armor were imposed by the Air Force and closely monitored by the SPO, but maximum possible design freedom was left to the company.

For the CPP the program director supervised a company team composed of representatives from all levels of engineering and manufacturing with design and manufacturing holding equal status. The project team was physically located in one area allowing constant formal and informal interaction to take place. Close coordination had been practiced by the company in regard to producibility for many years,

but never before so thoroughly at an early stage. Productivity usually was considered after the overall design shape was fixed, but in this program design-cost feedback occurred at the design table where a tooling expert might reject a design sketch as too expensive to execute before it was even drafted. Alternative proposals and suggestions were made early resulting in a highly cost conscious design effort.

The organization for designing to a cost was effective, but the initial problem to face the program director and his staff was to create an attitude of cost consciousness in the designers. The problem was really one of changing the traditional methods and procedures of designing an aircraft from a concern with performance to a concern with cost. It was necessary to re-orient the design subculture by inculcating an awareness of the objective of achieving design goals at minimum cost. Every designer had to learn that the impact of cost in design decisions was exceedingly important.

Constant communication between the SPO and the company and among the functional disciplines at Fairchild-Republic accomplished the goal of incorporating cost conscious design at the earliest stages.

The Air Force activities outside of the SPO providing support to the program did not, and still do not, have the cost consciousness of the SPO. The contractor program director felt that these agencies were in need of reorienta-

tion to the same kind of design to a cost commitment evidenced by the SPO.

The Fairchild-Republic program director also found it necessary to insist that vendors and subcontractors develop this same design to a cost attitude. It took some time and effort to convince vendors that if Fairchild-Republic was buying a subassembly or a component from them the company expected the vendor to make trade studies of its own and provide lower cost options. For example, a landing gear subassembly proposed by a vendor was rejected on the basis of cost alone. In that particular case the supplier was redirected to design to a cost. Just as the SPO was remaining detached from the aircraft design but insisting on cost effective design, Fairchild-Republic was insisting that the vendor bring his experience to bear in providing the simplest and least costly design for an effective job.

There were three significant design decisions taken which formed the foundation for the Fairchild-Republic aircraft design for the A-X. The first was the decision to make a prototype as near the production aircraft as possible. The second and third related to the engines and resulted in the aircraft configuration selected.

The company proposal began as a formulation around the way the project team read the RFP. It was the opinion of the program director and his staff that prototyping afforded a choice between two opportunities. First they could build two prototype aircraft designed to meet the target production

cost as cheaply as possible using fabrication techniques which would be modified for production. This might result in an aircraft lower in performance, or heavier, or degraded in some other way, but still demonstrating a basic design from which data could be extrapolated to the production version. The second choice would be to build two aircraft as near to the production version as possible which would demonstrate the design and the performance to be expected in the production version.

Fairchild-Republic chose the second approach even though it represented the higher cost of the two choices. As they read the RFP the criteria for design selection would be production target cost and technical adequacy; the cost of the CPP was not a prime competitive element. Some of the company's reasons for choosing the higher cost approach are the validity of the flight test data, demonstrated operational suitability and performance, the "second look" in manufacturing when going into production, the establishment of a starting point on the learning curves, simplified prototype to production transition, the credibility of estimated production costs, etc.

The principal design decisions leading to the configuration selected resulted from engine and wing airfoil trade-off studies. One result was that the higher thrust engine, General Electric TF-34, was selected even though it was the higher cost engine of the two available. This engine permitted the use of a higher lift-higher drag, cheaper to produce,

moderately thick and highly cambered airfoil for the wing. The decision to mount the engines externally permitted a much simpler fuselage design embodying simple external lines, single curvature, constant cross-section and multi-usage parts.

The selection of the TF-34 afforded many tradeoff opportunities as well as reduced technical risk since the engine is a new, model qualified test engine in the DoD inventory. The non-recurring development costs would be minimized and, since the engine was already qualified, it would need only requalification for those changes made for the A-X.

The absence of specifications and detailed requirements permitted additional tradeoffs between engine and airframe weight in order to reduce costs by about \$45,000 per aircraft. The fuel heaters were removed, titanium was replaced with steel and high cost processing to remove weight was eliminated. The resulting engine was approximately forty-five pounds heavier. The cost reduction was traded against weight penalty at the rate of \$1,000 per pound. In Republic's experience airframe weight can be reduced at a cost of about \$75 per pound; Fairchild-Republic accepted increased engine weight and reduced airframe weight at a net savings of \$925 per pound.

The higher thrust engine also exhibited a better specific fuel consumption providing further opportunities for tradeoffs in design features to reduce airframe costs. The higher tolerance for protuberances of the higher thrust-

lower fuel consumption engine permitted the use of external brazier head revets and lap joints on the fuselage, and the wing attach bolts have bolted flanges covered with an aerodynamic fairing. In every case where aggregated cost estimates indicated that the design target cost was being approached further tradeoffs were studied and made.

Manufacturing design team members decided on the most economical and manageable job sizes in assembly, then they asked engineering to provide splices at those places. Design for producibility also resulted in simpler and in some cases interchangeable structural elements. Identical left-right parts include the assemblies such as built-up engines, vertical tail, main landing gear and stabilizer ribs. The simple design will enhance reliability and the interchangeability will permit a reduced spare parts inventory having some beneficial effect on life cycle costs.

The fabrication of the design was entirely within the state of the art. Even though promising techniques were investigated and their development will be continued, technical risk in manufacturing was eliminated from consideration. Numerical (tape) control permitted some imaginative assembly techniques. The wing is built in three sections and the sections bolted together as a cheaper alternative to building the wing in one piece. Numerical control of the drilling of the attaching holes, an interface requiring critical accuracy, makes wing construction simpler and permits interchanging in the field.

Risks were perceived to be of three types in the CPP; technical, schedule and cost. Technical risk was minimized by choosing the proven technique wherever possible. Schedule risk was minimized by milestoneing to keep a high level of visibility. Cost risk was minimized by the low level of technical risk involved and by building prototypes which represented production articles as nearly as possible. By keeping track of part costs and by using learning-experience curves, the production estimated costs were based nearly on actual experience.

In the design process cost estimating was accomplished by detailed engineering analysis of each part and then aggregating the estimates to reach an estimated total cost. The resulting estimates were then confirmed through the use of parametric estimating techniques. A small problem encountered with regard to cost estimating is the relationships used by evaluators at Air Staff and DoD levels. One of the most fruitful techniques employed to reduce A-X costs was to accept higher weight in certain areas. The relationships used for evaluation of a contractor by higher staff levels does not allow for higher weight to be accompanied by lower cost. All of the rulebooks equate higher weight with higher, not lower, cost, and the approved cost reduction technique demands that weight be reduced. This deficiency is not terribly significant, but it does point out that design to a cost might have to suffer the disadvantages of breaking new ground or requiring some new evaluative procedures.

The influence of the using command can still prevail in some cases against the judgment of the SPO and the contractor. Because Fairchild-Republic determined from the engine manufacturer that running the TF-34 at idle would have no significant effect on engine life, the design team eliminated the auxiliary power unit from their A-X design. At the insistence of the using command the APU was put back in the aircraft. That APU remains a tradable item and if costs are found to be approaching or exceeding the target cost the APU can be eliminated.

AIR FORCE ISSUES IN PROGRAM DIRECTION

The issue of problems encountered in directing a design to a cost program was pursued with only the A-10 SPO. The SCAD program was not a design to a cost program, and the AMST program has been in existence only a comparatively short time. The A-10 program office has had more than three years of experience in working with design to a cost. In the course of this time the function of program direction has been performed with cost as the primary decision parameter. The A-10 program can, therefore, be presumed to have received direction different from programs which do not give cost such a high priority. The SPO has a unique background for providing insight into the problems in decision making and program direction under the design to a cost concept.

The first step was to try to determine what the program director does differently under design to a cost. The

answer appears to be just about everything, excluding internal administration. There is no subset or category of program decisions for the SPD to consider which are outside the scope of design to a cost. Cost is the most important parameter in the A-10 program.

Beginning with the preparation of the CPP/RFP the SPD made decisions on what would be included as a requirement and, perhaps more importantly, what would not be included. The CPP RFP was followed by instructions for the proposals to be submitted by the two contractors competing for full scale development. Every specification and standard contained in the proposal instructions had been individually evaluated and approved by the SPD. Offerors were required to submit cost tradeoff studies on certain specific items and subsystems and were encouraged to submit any trade/cost impact studies they thought appropriate. The decisions made based on the trade studies provide indications of SPD actions taken with cost having the highest priority.

These decisions also provide indications of the conflict between cost and requirements. The requirements process was excluded from this study insofar as what goes into establishing system performance goals. But the requirements process can, and often does, continue through the development phase into the production and deployment phases. Engineering changes are usually sought to correct a deficiency or to satisfy a new requirement.

The use of the design to a cost concept does not preclude changes in the system, but the SPD use of cost as a primary decision parameter insures that the cost impact of changes are evaluated against the benefits obtained. An SPD decision to accept a proposed change in the A-10 would be more probable in the case of correcting a deficiency than it would in satisfying a new requirement. The A-10 contract for full scale development was signed in March 1973, and for the following six months the total number of engineering change orders was zero.

For the A-10 SPD the conflict between design to a cost and increased capability was not limited to changes. Several subsystems were intentionally left out of the prototype aircraft even though they would be required in production aircraft. The program is currently involved with two different types of requirements for production subsystems. The aircrew escape system recently required a decision between cost and additional performance. Some avionics, such as the head-up display (HUD) and the ARA-50 direction finding radio, are under study and will be decided based on cost versus performance. The other type of requirement is for growth potential as opposed to sufficient present performance.

The decision on the aircrew escape system is perhaps the best example of the cost versus performance conflict which must be decided by the SPD. But this particular decision appears to have been a very important one to the cost-requirements conflict. It is believed that the future

viability of the design to a cost concept, at least in the A-10 program, was dependent upon the outcome.

Two different escape systems were proposed for the A-10, the ACES II and a version of the ESCAPAC. The meaning of the acronyms and the details of performance of the two systems are unimportant for this discussion. There are two differences significant here between ACES II and ESCAPAC: ACES II is more expensive, and the ACES II capabilities encompass a larger envelope of flight conditions. Within the flight envelope of the A-10 aircraft both escape systems show similar performance. In fact, one opinion voiced at the SPO was that within the A-10 flight envelope the capabilities are so similar that a line drawn with a felt-tipped pen would cover both graphs. The performance of the ACES II is superior to the ESCAPAC outside the projected envelope of ejection conditions for the A-10, but only slightly so inside that envelope. In order to keep the discussion in perspective it should be mentioned that both escape systems have capabilities which exceed those of any escape system presently installed in a production fighter. The comparison, then, is between two superior escape systems. The decision had to be made based on cost and adequate performance versus cost and the best performance available. The SPO decision was for the cheaper, adequate ESCAPAC. The using command and aeromedical specialists held out for the best performance available and appealed to higher command levels. The resolution of this conflict between cost and performances

would go to the very heart of the A-10 design to a cost effort. The SPD wanted adequate performance at lowest possible cost. The requirements people wanted the best available performance at whatever it cost to get it. The final decision was made by the Air Force Chief of Staff in favor of the ESCAPAC and, by extension, of design to a cost.

The requirement to buy growth potential is exemplified in the TF-34 engine. The A-10 program office chose to buy adequate performance and to spend no money to enhance the growth potential of the engine. The jet engine purchasing experts at Aeronautical Systems Division (ASD), who buy all jet engines for all U.S. Military applications, think that it is a mistake to disregard growth potential and focus too narrowly on a specific application. However, the TF-34 was originally developed for the Navy's S-3A Viking aircraft and modified specifically to reduce costs for the A-10. The modified version has now been adopted for use in the S-3A raising the question of the value of what was so expensively included in the first place. Other examples are the HUD, ARA-50 radio and target designation avionics/optics also being bought for present performance and not for growth potential. Nine HUD's are being evaluated by the contractor, the ARA-50 is an Army development, and the Air Force does not yet have the equipment to utilize the laser device that the using command wanted. The A-10 SPD is not buying potential utility, he is evaluating alternatives and buying adequate performance at least cost.

To return to the question of what is done differently under design to a cost in the A-10, decisions are made based on cost. There is an attitude in the A-10 program that the only difference between design to a cost and any other concept is the commitment of the user to cost. There must be a conviction that cost is more important than additional performance. There must be a conviction that adequate performance is good enough. There must be a conviction that the system can be designed for its mission within the target cost.

The authority of the program manager to direct his program must be supported by a commitment to the design to a cost concept at all levels. The commander of ASD exercises close supervision of the A-10 program. No engineering changes can be made without his knowledge and approval. The support for the SPD's decision on the escape system reached all the way to the Chief of Staff.

In summary, then, the A-10 design to a cost implementation has not encountered serious problems. Initial Fairchild-Republic uncertainties about Air Force intentions with regard to cost priority were overcome, and the company project team committed itself to the concept. Early operation was hampered by inadequate cost consciousness among the designers on the team. Effort had to be put into educating the design sub-culture in the importance of cost and of searching for less costly alternatives. Vendors and suppliers were required to adopt design to a cost. They were encouraged

to identify tradeoff possibilities and alternative proposals. Close coordination between design and manufacturing had to begin very early in the design phase.

The A-10 design has met the target cost and performs acceptably. The careful composition of the RFP and proposal instructions were factors in the success thus far achieved in the program. The establishment of a realistic, achievable, unambiguous cost target also contributed to the success achieved. The commitment of the SPO and the Air Force hierarchy to the priority given to cost kept design to a cost operational in the A-10 program. The conflict between cost and requirements was resolved for this program in favor of cost. It is believed that a potentially serious problem for the design to a cost concept was thus avoided.

VI. AMSTGENERAL

The Air Force Advanced Prototype Program is a series of prototype acquisitions made to provide hardware for test and evaluation of design, technology and military usefulness by the Air Force. The Advanced Medium STOL Transport (AMST) is one of the prototype programs in this series. The AMST grew from a need identified by Tactical Air Command for an updated intratheater airlift capability. A study report presented to Deputy Defense Secretary Packard in September, 1971, resulted in RFP solicitations to industry for a limited prototype program. The proposals would be used to evaluate future options available to the military. The program is not a weapon system acquisition and is not subject to the normal requirements for periodic review by the DSARC. Instead, it is a limited life program with limited objectives.

The objectives of the AMST program stated in the RFP are to:

(1) design, fabricate and evaluate a prototype aircraft which will demonstrate in hardware, new technology, which after additional engineering development will provide a medium sized (C-130 class) jet STOL transport; (2) provide a low cost development option for modernization of the tactical airlift force; (3) obtain visibility on costs associated with short field performance; and (4) define STOL operational rules, safety rules, and related design criteria.

In the past the incorporation of newer technology has in some manner implied an increase in "goodness" of the

product. The AMST program involves new technology but does not envision buying it at any price. New technology will be bought only as necessary. In the AMST program the new technology for which the program was begun is aerodynamic in nature and has been the subject of investigation and small scale testing for a long time prior to this program. In this regard the AMST is essentially demonstrative and not investigative in nature.

Prototyping was chosen as the approach to be taken toward achieving the objectives. Two contractors are required to design, develop, fabricate, test and support two prototype aircraft. The focus is on a prototype which can be developed into a simple, maintainable, reliable, low production cost aircraft which, with additional engineering development, could provide a medium sized, jet, STOL transport. From the Air Force point of view there is no competition for a forthcoming production contract because there is no production currently contemplated as the outcome of the prototype phase.

AIR FORCE ISSUES

The Commander, Aeronautical Systems Division (ASD) at Wright-Patterson AFB, is the source selection authority for the AMST procurement, and in his letter requesting proposals he established three significant features of the program. In the first paragraph of the RFP the maximum available resource was stated: "Funds for the total program will not exceed \$180 million inclusive of GFE/GFAE." (1:1) The

effect of the funds limitation imposed was to make the entire prototype phase something of a design to a cost effort.

The second point of significance was the statement of intent with regard to production: "Award of a prototype contract implies no commitment, whatsoever, on the part of the Air Force toward future prototype, engineering development and/or production programs." (1:1) Nevertheless, the perception of the possibility for a production contract despite the above disclaimer injected a strong competitive element into contractor efforts.

The third point of significance made in the RFP is the design to a cost target:

...it is our objective that any prototype proposed be consistent with a future production model which could be procured for a maximum of \$5 million in FY 72 dollars.
(1:1)

This is the only specific reference to a dollar figure made in the RFP, and it should be noted that the figure is stated as an objective.

In January 1972 solicitations were sent to nine aerospace companies whose general size and experience qualified them for possible participation in the AMST development. Seven proposals were received from five sources. After evaluation of the proposals awards were made to two firms in November 1972. The initial proposals reflected the view that the cost target was a goal and not a ceiling. The initial awards appear to have been made basically to correct for a faulty communication of the importance of the production cost target since the award limited the effort to a

Phase I Study. The Phase I Study, completed within two months, permitted the contractors selected to reaccomplish their proposals sufficiently to meet the design to a cost goal of \$5 million unit flyaway cost at the three hundredth unit.

Phase II design and development effort was authorized in January, 1973, by contract modification. Douglas Aircraft Division of McDonnell-Douglas and Boeing Company were the two contractors selected to design, develop, fabricate, test and support two aircraft each.

The contractors were chosen through an evaluation based on the following criteria: contractor capability, technical approach including design and performance goals, the prototype development effort, and costs. The relatively lower priority of costs in the stated evaluation criteria makes the misunderstanding by contractors of the design to a cost target understandable. The contractor proposals were made based on their experiences in previous acquisitions where cost goals were less important than performance goals. The Phase I Study award brought the importance of cost, specifically the design to a cost goal, into sharp focus for the contractors.

Each of the contracts has a provision fixing the maximum cost liability to the government of the prototype effort. Both contracts were awarded to pursue a common set of goals. The Douglas contract is a cost sharing contract with a total government share of approximately \$86 million, and the Boeing

contract is a cost plus fixed fee (CPFF) type of contract with a total value of approximately \$96 million.

Air Force evaluation of the prototypes will include a flight test program conducted by a joint test team. The test team will have representatives from the contractor, Air Force Flight Test Center, TAC, AFLC and NASA, and the program will include information from the Army and Marine Corps. The aircraft will not be in operational configuration and will not undergo the operational testing and evaluation. The AMST is not a weapon system program, it is a prototype program and is therefore not to be tested as a weapon system.

In the prototype phase there will be no actual flyoff between the different aircraft. The joint military-contractor flight test program should demonstrate proof of powered lift concepts, flight control response characteristics, application of the prototype-exhibited characteristics to the tactical airlift mission, etc. The purpose of the flight test program is, like the entire AMST effort, to develop technology and to provide data to use for consideration of further development of medium transport, STOL aircraft. The evaluation will include operational suitability and prototype to production transition.

The AMST is a limited life, limited objective program with no production avionics or cargo handling systems to be included. Before a production decision could be contemplated the design would have to be assigned to a specific

mission and fitted with the required systems and equipment. There are no USAF or DoD decision points scheduled or needed in the program as presently structured.

There is little explicit reference to competition other than that which led to the awards to the two out of five companies bidding in the first place. But the aura of competition for a production contract pervades the contractor efforts. The AMST prototype program would provide little incentive for Boeing to produce two prototypes, and then to direct their efforts elsewhere. Or for Douglas to offer company effort to share the risk in development merely on the basis of possible commercial application in the vague and uncertain future. These companies need powerful incentives to induce them to participate. The prototype development of an AMST leads the major airframe companies to regard the possibility of a production contract as sufficient incentive to undertake the prototype program. Each contractor can be regarded as competing for a very uncertain production contract. Thus, his design effort has to take into consideration operational suitability, performance, prototype to production transition as well as the target cost of the design.

The maximum obligation of the government provision together with the unit flyaway cost target face each contractor with a double design to a cost effort. Each contractor must design his entire prototype development program to a maximum cost target, and each contractor must design

his aircraft to meet a production cost target. The Boeing contract provides the clearest example of the prototype phase cost constraint. Boeing is required, in order to collect the fixed fee as profit, to build and evaluate their design, designated the YC-14, within the \$96 million figure. If this is not specifically a design to a cost effort, it is certainly a manage to a cost effort. Moreover, the maximum dollar figure is as effective a constraint as though it were called design to a cost. Whether or not Boeing chooses to forego the fixed fee and even commit company resources to the prototype development is a question beyond the scope of this study, however interesting and intriguing. Just what their top management is motivated to do depends on what the company perceives its total competitive position to be for the short and the long term.

Less clearly a manage to a cost effort is the Douglas cost sharing contract with its \$86 million maximum obligation to the government. The specific amount of the dollar commitment by the company is unimportant here, but the fact that the Douglas proposal included a significant commitment by the company, on the order of one third of the total program costs, indicates the extent of company interest and motivation. The parent McDonnell-Douglas company had been involved in a cooperative effort with two domestic airlines and the French manufacturer of the Breguet 188 STOL aircraft to evaluate the commercial feasibility of STOL operations. The company interest in an AMST could be presumed to stem

from this program. Or, the motivation to offer to share development costs might result from a complexity of factors including remaining in STOL business by competing vigorously for a continuing share of the market.

Whatever the motivation the need to manage the prototype development program to a specific cost is less constraining to Douglas than it is to Boeing. Increasing the initial investment in their design can become a company decision on a company venture by simply expanding company participation. The dollar limit constrains the YC-15 program manager but is not so severe a constraint on the company.

The different contracts and the different cost constraints on the prototype phase act together to effect a competitive relationship between the YC-14 and YC-15. There is no explicit competition for a production contract, but the two contractors seem to be performing based on that kind of incentive.

The design to a cost target for the AMST was specified in the 24 January 1972 RFP as \$5 million in FY 72 dollars. Further guidance was given by the ASD commander at the Bidders' Briefing on 8 February 1972:

...First of all, the \$5 million figure is defined in this manner. \$5 million is the expected flyaway cost in FY 72 dollars of a 300th production article, in a reasonably paced production program, which might evolve from your prototype design...

Two points in this definition of the cost target are worthy of note, and one of these two is significant. The rate of production is not specified but was to be based on reasonable

and representative figures. It appears that informal agreement was reached that a production rate of five aircraft per month would fit a projected reasonably supportable budget of \$300 million (sixty aircraft) per year.

The \$5 million figure is the unit flyaway cost for the three hundredth article, and further clarification during questioning at the Bidders' Briefing refined the definition to unit recurring flyaway costs including GFE/GFAE. Since the rate of production was not specified, the target cost could not include non-recurring costs as these are dependent upon production rate. From the standpoint of cost control the significant part of the definition is the specification of the three hundredth unit as the one which must meet the target cost.

In his review of the nineteen DoD Design-to-Cost Programs Mr. James McCullough parenthetically notes the shift from cumulative average cost as a design target in the A-10 program to the three hundredth unit cost goal of the AMST program. The three hundredth unit can be plotted on a typical learning curve against a specific cost, such as \$5 million. By this process the recurring flyaway cost of each other unit in the continuous production of a standard model can be determined. The cost of any one unit, any group of units, or even the cumulative average of all units to be produced can then be easily calculated.

The presumption inherent in such a process of cost calculation is that the learning curve can be plotted as

a straight line on log-log graph paper. As a summary of past experience a learning curve can be plotted for virtually any and all phases of a manufacturing process, particularly of a labor-intensive one. The learning curve so plotted can be valuable in predicting the decrease in cost over time or units for a similarly defined cost in a similar manufacturing process.

But learning curves are manipulable in some cases, and where the defined cost is only a part of the total cost the learning curve can be driven to whatever shape and slope desired. The cost target for the AMST is unit recurring flyaway cost, and unit recurring cost can be made to vary inversely with non-recurring cost. For example, investment in automation and mass production facilities and tooling can result in a steeper than otherwise learning curve fixed at the point where the three hundredth unit costs \$5 million. In this case the cumulative average unit cost for the three hundred units would be higher than it should be. Learning curves can even be made to be convex or concave from the first to the three hundredth unit, either of which could be beneficial to the buyer depending upon the numbers bought.

The use of the cumulative average unit cost target would not prevent excessive non-recurring costs from forcing the acquisition costs higher, but it could eliminate unexpectedly high costs which would result from altering the manufacturing process to give the learning curve desired for \$X cost at the Yth unit. Cumulative average unit cost target

allows the manufacturing process to be selected to give the most advantageous learning curve for the total number contemplated for purchase.

Both Boeing and Douglas have received requests to provide to the SPO estimates of the cumulative average unit recurring flyaway cost for a total of three hundred units. The government is apparently finding that the cost at the three hundredth unit is not sufficient to provide the type of cost tracking they require.

The failure of the Air Force to be satisfied with its own cost target raises questions in the contractor program offices concerning Air Force intent with regard to other facets of the AMST program. There seems to be less confidence in the credibility of the Air Force position. Does the Air Force really know what it wants? Is the Air Force saying what it wants? First of all, the failure to adequately communicate the importance of the production cost target to the offerors in part led to the award of limited Phase I Study contracts. These contracts were modified to permit design development only after the Phase I results showed that the production target costs were achievable by each contractor. Now the specific unit is replaced by cumulative average. An understandable reaction on the part of the contractor would be frustration at not being told of the important features in time to evaluate alternatives before proposing a design and a complete prototype program.

An additional issue concerns possible production when the design is frozen to a producible configuration. What other factors, perhaps unknown to the Air Force program management at the present time, might have an effect on selecting this design or that design for production? Are there other criteria which might fit in the evaluation of either prototype and cause one or the other to accidentally assume a significantly better chance of selection? Will such factors as noise pollution, the energy crisis, fuel costs be subsequently imposed as criteria by some higher level in the government? These factors impact directly on engine selection, engine selection impacts directly on configuration, and configuration impacts directly on unit recurring flyaway costs. Will cost remain of the highest priority in evaluation if the AMST is chosen to modernize the TAC airlift capability? The question is only important if a production decision is contemplated for the designs demonstrated in hardware. The AMST does not have a production decision expressed or implied, so the question is academic. However, as brought out earlier the contractors are proceeding as if a production contract will be awarded.

CONTRACTOR ISSUES AT DOUGLAS

In an address to the Dayton area chapter of the American Institute of Aeronautics and Astronautics in May of 1973, a vice-president of the McDonnell-Douglas corporation, explained that the company approach to design to a cost in

the AMST was to trade off performance requirements with cost. The company has been designing airplanes to cost targets for commercial applications as a usual practice for a very long time. In proposing a commercial aircraft for a sufficiently large market the price offered by McDonnell-Douglas to purchasers is based on preliminary design information, and this is the price which is contractually agreed upon.

The commercial aircraft producer employs a large number of designers and engineers whose training and experience in the commercial sector makes them somewhat aware of the impact of cost in design. The commercial aircraft design subculture seems to be concerned primarily with function, safety and performance but there is general agreement that cost is given at least some consideration by most designers. From the company standpoint the unit selling price is composed of many parts unaffected by aircraft design features, and the rigorous application of cost discipline is not as important as marketing. The ultimate determination of the profitability of a commercial design lies in the selling of some number of units higher than the break-even number. The impact of varying unit recurring flyaway costs is the moving of the break-even point to a higher or lower number which is a marketing problem, not solely a high cost design problem. The ultimate determination of the profitability of a military design (idealized) is the ability to make a fixed number of aircraft at a cost

lower than the contractually agreed figure. There can be no reliance on selling more aircraft than originally planned if the break-even point was driven outward by higher design costs; the sales figure is fixed.

Another, perhaps lesser, problem faced by the commercial aircraft producer estimating the cost of a military product is the use of commercial data for the military program requirements. For example, some of the learning curves for a DC-9 or a Boeing 727 reflect a sawtooth appearance due to the block releases of small numbers in a single configuration. Each new block release would cause a jump in the learning curve, particularly due to changes of labor-intensive items like interior furnishings. The learning curves for a spartan and unchanging military aircraft design would be steeper and would start from a lower point. The company does not know how much steeper and how much lower from its commercial data, and accuracy of the highest order is not obtainable. However, when designing to a cost a company must be able to estimate costs as accurately as possible. These are important considerations within the company which become problems in the cost estimating process when cost is a primary parameter.

The Douglas YC-15 jet transport has four Pratt & Whitney JT-8D engines pod-mounted beneath a high, unswept wing. Some advanced design features include a supercritical wing, advanced flight control system and externally blown flaps technology to provide power lift for STOL performance.

The four-engine configuration was chosen basically for operational reasons, first of all because of engine-out characteristics and safety considerations. Additionally, the configuration was thought to offer better possibilities for overseas sales. When sales history of the C-130 was reviewed it was found that while the USAF uses the C-130 for intratheater airlift many foreign purchasers use the C-130 as their primary, long range transport aircraft. The four-engine configuration was considered to offer a better chance in the overseas C-130 replacement market.

The RFP specified turbojet or turbofan powered transport aircraft with cruising speed. The normal design approach to achieving the typical mach .7 to .8 range of modern jet aircraft has been to sweep the wings back. The swept wing is much more difficult and costly to manufacture than a straight wing and is therefore an obvious target for cost savings. The availability of supercritical wing design made possible the tradeoff of some cruise speed from the swept wing for the lower cost of the straight wing. Incidentally, the wing tradeoff sacrificed no STOL performance, stability or control.

The cargo compartment size specified in the RFP was twelve feet by twelve feet by fifty-five feet, effectively dictating the fuselage size. Fuselage design was simplified into a cylindrical section for as much of its length as possible for ease of manufacture. The size of the cargo compartment was actually reduced by under one foot in height

and width in a further move to reduce costs. This specific tradeoff was made knowing that a few basic items could not be carried in the smaller compartment. In the empennage area some one hundred thirty-nine unique assemblies were reduced to a total of five. Even the selection of the JT-8D was a compromise in performance made to eliminate development and non-recurring costs.

The prototype to production transition of the YC-15 design was a strong factor in choosing to build a reproducible prototype. The production configuration is fixed, but, since this is a technology demonstration program, stress measuring devices have been designed to be built into each prototype. As a result, some engineering re-design would be required for production.

Organizational problems might be expected as a possible result of the implementation of design to a cost. Douglas has been very conservative and has avoided breaking new organizational ground so as not to create a problem similar to one they had previously experienced. Douglas had a difficult experience at the time of the proposal for the C-5A contract in that they made permanent assignment of functional specialists to the program office only to find at the termination of the effort that there was considerably dislocation brought about by the wholesale reassignment of the specialists. There was no great need for them in any other program, and the offices they had left had found replacements for them and could not reabsorb them.

The Douglas YC-15 program organization is a fairly straightforward project-matrix type in which the program manager has complete control over the project effort, but he does not have total control over the members of the program office; they retain their identification with one of the functional organizations. Motivation of designers toward greater cost consciousness is the design to a cost effort has not been difficult to achieve, and a variety of personnel action incentives are available to the program manager to enhance the overall effort.

The organization of the AMST effort was not unique to this program because it was a design to a cost effort. The design to a cost nature of the program did require much closer coordination very early in the preliminary design stages, and manufacturing was represented from the earliest iterations through the design cycle. The competitive history of the company would dictate, if nothing else, that the producibility of an design would be an important consideration. But the significant cost decisions take place before the design is frozen. In the AIAA speech by the vice-president for production said there is only a five to ten percent vernier on cost changes once the design is frozen. The Douglas YC-15 program team do not consider that their aircraft design is pushing the state of the art. They do not consider that the lower surface blowing technique is a new technology, and they are not using new materials, processes or techniques in manufacturing.

The Douglas design to a cost effort did encounter the same kind of problem in the designer subculture that was found by Fairchild-Republic. That is, the designer was typically not as concerned with the cost of his design as he needed to be. For Douglas the problem was not of the same magnitude because the commercial designer has cost in closer focus than the performance-oriented designer for the military application. The focus was simply not sharp enough.

CONTRACTOR ISSUES AT BOEING

The Boeing YC-14 jet transport is a twin-engine design with two General Electric CF-6 engines shoulder mounted on the upper leading edge of the wing. Jet efflux passing over the top of the wing provides powered lift through upper surface blowing technique. As in the YC-15 the YC-14 uses an unswept, supercritical wing and an advanced flight control system for positive response in the low airspeed regime in which this STOL aircraft will operate. At the present time the YC-14 design has not been frozen and is not expected to be until October, 1973.

The imposition of the design to a cost concept forced design decisions similar in nature to those of the A-10 and the YC-14. Basic design decisions were made with the total cost impact weighing heaviest, but other factors were considered. The two-engine configuration was chosen based on both the cost of the production article and the dollar limit imposed on the prototype phase by the maximum obligation

of the government provision in the contract. The configuration offers additional advantages of using the latest in engine technology, systems simplicity with reduced maintenance, operating economy, and more advanced lift technology. The design is the more risky of the two configurations being demonstrated because of the advanced engines and lift technology. But Boeing also thought that this configuration offered the best promise of performance within the cost constraint. Upper surface blowing makes use of the phenomenon called the coanda effect which has not yet been demonstrated in a large aircraft. The externally blown flaps of the YC-15 are different applications of lift generation known ever since propellers have blown over wings.

The straight wing provides the same cost economies already discussed in the Fairchild-Republic and the Douglas design tradeoffs, and fuselage simplification to reduce cost includes the constant diameter mid-body section and straight line elements where possible. The engine nacelles are interchangeable, the left and right hand stabilizer boxes are interchangeable, and the fin is of constant chord and thickness with common leading edges, ribs and rudders. The primary material is aluminum in sheet/stringer construction. In the YC-14 as in the YC-15 the imposition of a production cost goal has eliminated advanced structural procedures. In the prototype program Boeing is using parts common to the 727-737-747 aircraft wherever possible to keep costs down.

The cost-performance tradeoffs made to achieve a design cost goal appear rather simple and easily made. The large impact, overall design trades appear deceptively simple to make, and the rest might be airily dismissed as another exercise in value engineering, but there is no facile categorization of big and small decisions. Big decisions are often made based on many small decisions evaluated at some aggregate level. In the earliest design studies design to a cost is being implemented to far lower levels of indenture in a work breakdown structure in order to quantify the effects of design decisions.

The Boeing implementation of design to a cost in the AMST is probably representative of the effort which would be put forth by any of the large aerospace manufacturers in a similar program. The Boeing approach depended upon the ability to fix the cost of each component or assembly as nearly as possible and then to validate that data by comparison to hardware experience. The Boeing effort was doubly constrained as to cost, the production cost target and the maximum obligation limit in the contract. The result was to force the minutest examination of the design-cost interrelationship.

Crucial to the ability to design to a cost is the ability to definitize in the design phase each part, component, subsystem and assembly--a staggering amount of detail so early in a program--so that the total cost can be estimated with reasonable accuracy and a category of costs

for at least the known-unknowns eliminated. A program involving a significant level of technical risk might be susceptible to a cost "bogey" approach to bound contractors, but the weapon system would not, by definition, be designed to a cost. The cost of alternatives must be known.

The arrival of the design to a cost concept at Boeing was received by many as another fad system created to generate paperwork and harass government contractors. With much scurrying in search of how-to-do-it assistance, manuals on designing for cost to produce, etc., the awareness gradually grew that designing to a cost was not a new or unique system. The attitude which now pervades the YC-14 program is that design to a cost is done the way the contractor chooses to do it with whatever system he wants to employ. The concern with cost is of prime importance and the Boeing system has been adjusted to emphasize cost and design-cost interrelationships from the earliest stages onward. Design to a cost is not a DoD-imposed system, but it is a systematic approach to controlling product cost through design actions.

The design group is organized into Work Package Teams composed of representatives of each major functional specialty including all levels of manufacturing and engineering. The design representative is the team leader during the design phase, and the team will remain intact through the completion of the two prototype aircraft with the manufacturing representative taking control of the team for fabrication and assembly.

The prototype phase budget allocations were made by Boeing, not imposed by the government, based on their experience and were distributed down to level 5 in the work breakdown structure. Each Work Package Team created a detailed description of what was required in that work package to include design guidelines, detailed sketches and descriptions, manufacturing processes, etc., in far greater detail than had been done before in the commercial division. For example, "...similar to (part number so and so)," common practice in commercial design, was insufficient description in the AMST design to a cost.

The work package information created was gathered together into a book whose contents corresponded to the WBS level 5 form on which the budget allocation had been recorded. The form had a second column for recording the detailed cost of manufacture estimate made by the team giving immediate visibility to disparities between budget and estimate. The need for intensive design effort in a certain area, the availability of overallocated budget, or the absence of any discrepancy can almost be read right from the level 5 form. A third column on the form is reserved to recording actual costs experienced in the prototype phase. This assists cost tracking considerably and provides yet another look at disparities between estimated and actual costs. Having this information available becomes important for engineering re-design in the event that full scale development is contemplated.

From the start the designers were unhappy with the amount of detail and paperwork that went into the creation of a work package book, but the close coordination made the cost impact of any given design decision immediately available to team members and early cost emphasis was achieved. As the teams got accustomed to the detailed work package design method the designers grew grudgingly but gradually happier as they found their later work found simpler; design problems were identified earlier and dealt with earlier before features got locked in.

The YC-14 estimates were validated with experience. Boeing has a vast amount of experience with the 727 aircraft and created a base line for the YC-14 by comparing estimates for the YC-14 with actual data from the twenty-to thirty-percent smaller 727. Because of the difficulty of reducing learning curves from the commercial experience to the military requirements care had to be taken to factor out those effects of small number block releases. This left data which could be applied to the military prototype program.

Boeing does not consider that the YC-14 program has very much technical risk in it. They see it as a state of the art airplane merely demonstrating a proven lift technology. Manufacturing processes are simple, and the company capability to manufacture large parts for the 747 permits cost savings in YC-14 design. The company has a machine which can make the one hundred ten foot long, straight, main spar for the

center wing box structure in one piece with no splice required. Program representatives felt that Boeing would not have bid if they had foreseen much risk. Boeing proposed a reproducible design, perhaps in the hope of winning the production competition. An opinion expressed by one man holds that everything has to go extremely well in order to make money on the prototype, and the production target is very close to impossible.

Because there is no unknown or undefined element in the YC-14 the design group was able to assign a cost based on engineering analysis to the design of each part, component or subassembly with a very high level of confidence. The absence of uncertainty was fundamental to their ability to design to a cost.

In summary, the AMST program suffered initially from some uncertainties about the importance of cost. The RFP did not provide a sufficiently detailed and emphatic statement of the priority to be given to cost. The established target cost dollar figure appears to be reasonable and achievable, but the target cost is apparently not attached to the cost definition most effective for tracking. The provision in the contracts limiting government obligation is proving to be a constraint on the contractors, but whether or not that constraint is severe will not be known until the program is complete and can be evaluated.

Boeing and Douglas encountered the same inadequate level of design cost consciousness in the designer as that

found by Fairchild-Republic. Education and coordination overcame this particular problem. Both contractors have found that the design to a cost concept is proving beneficial in unexpected ways. Detail design is required early in the design phase, and design and manufacturing problems are exposed and corrected earlier than ever before.

The AMST program has not encountered any serious problems thus far in implementing design to a cost. There are, however, no undefined or technically risky elements in the proposed prototypes. The absence of uncertainty or risk was thought to be crucial to the ability of the design teams to design to a cost.

VII. CONCLUSIONS

The objective of this study was to examine some examples of design to a cost concept applications in the aerospace industry to learn what problems were caused by the implementation of the concept. The problems which could be identified as significant to the design to a cost concept fall into the general categories: communication, culture, operation and applicability.

A corollary objective of this study was to infer, where possible, from the facts or circumstances in which a problem was found, guidelines for future applications of the design to a cost concept which might help to avoid similar problems in the future. The conclusions drawn in this study are presented here by category including whatever recommendations are considered appropriate.

COMMUNICATION

There is thorough and common understanding of the design to a cost concept among those actually implementing the concept at the SPO and the contractor program office. Some current literature in the defense community expounds steps to be used or procedures to be followed before a procurement can be described as design to a cost. However, the view of design to a cost as a new procurement system is giving way to the view of design to a cost as a systematic application of cost as a primary design parameter.

Examples currently exist of over-use or mis-application of the design to a cost label. To avoid discrediting an otherwise viable concept through further promiscuous or erroneous application of the title an operating definition should be given widespread attention. For any given application of design to a cost the operating definition is the established goal and cost priority. A generalized definition for the concept is herewith recommended:

Design to a cost is the process of taking actions and making tradeoffs in the design phase which will keep the cost of the design from exceeding the established target cost while assuring that maximum capability is derived from the available resources.

The implementation of the design to a cost concept in the case of the SCAD and the AMST has failed to achieve an accurate communication of the Air Force intent for the program. The priority given to cost must be clearly stated. The importance of the specific cost target must be identified as target, ceiling, bogey or some other goal. Uncertainty concerning factors to be evaluated and the relative weighing of evaluation criteria must not be permitted to jeopardize the success of the program.

CULTURE

There is institutional inertia in the DoD weapon system procurement culture which must be overcome. The success of design to a cost depends upon the freedom of the designer to design unconstrained by specifications and standards

which do not guarantee a well designed system, but which often inhibit the design approach to a system. In the A-X and AMST programs the problem was dealt with from the start. Specifications were consciously and deliberately kept to a minimum. The proliferation of the "ilities" was restricted in the A-X and AMST.

The implementation of design to a cost in the contractor design teams encountered problems in the design subculture of the procurement culture. The severity of the problem is to some extent dependent upon the sales history of the contractor. All designers are by training and experience conservative in design with performance and technical excellence enjoying top priority. Failure in a part or component is a failure of the designer. Cost of the design materials, tooling, fabrication, finish, etc., are regarded as having a low priority. Design to a cost depends on a very high level of cost consciousness.

The contractor who has dealt primarily in with a performance-oriented military has the bigger problem in educating his designers and changing the design subculture to a cost conscious one. The contractor who has depended upon commercial sales in a business requiring a high level of cost effectiveness in design probably has the smaller problem in bringing about this cultural change. His designers have some higher level of cost awareness in their backgrounds.

OPERATION

The actual operation of design to a cost depends on credible, reasonable, achievable goals, proper timing and procurement methodology to fit the needs. The cost targets for the SCAD segments were variable while the operation of design to a cost requires the establishment of a firm cost target leaving design to a cost virtually without effect. The performance goals for both the A-X and the AMST were reasonable and achievable. However, the credibility of the AMST cost target and speed performance suffered from inadequate communication in the prototype phase RFP. The target cost for the AMST has proved too ambiguous; it is too easy to find different approaches to the specified \$5 million unit flyaway cost at the three hundredth unit. The Air Force is now asking for cumulative average figures from the AMST contractors. Establishing a cumulative average unit production target cost eliminates some of the uncertainty and possible manipulation of non-recurring costs to advantage.

To effectively use design to a cost a program must be in the conceptual stage. Design tradeoff decisions are among the significant few, and creative flexibility can be exercised in this phase. Once a particular system design is frozen a disservice is done to design to a cost by employing the phrase to describe value engineering or some other cost reduction system or procedure.

Design to a cost should be applied in a program which will permit the element of competition to be retained for as

long as possible in order to avoid having to negotiate with a sole-source contractor.

It would appear that contractual arrangements could be a problem if life cycle costing or operations and support cost guarantees are made elements of the target cost. In the programs examined in this study the use of both fixed price and cost reimbursement contracts has not generated unusual problems. The Air Force was wise not to consider the price of the A-X CPP contract primary in awarding prototype development contracts. The contractor assessed his needs and financial protection required and quoted a price, a price which gave the Air Force the prototype of a system designed to the target cost. The AMST cost reimbursement contract for the prototype phase had the added fillip of a maximum obligation to the government provision which had the effect of making the contract like a firm fixed price one. The contractors had to assess their needs and financial protection required and then accept the quoted price, rather than proposing a system to be built at a contractor determined price. Douglas responded by offering to share development cost while Boeing chose to attempt to manage to the maximum cost figure.

At the present state of cost data gathering and analysis and estimating, the design to a cost concept has been restricted to use for only a part of a weapon system acquisition cost. Better economic estimators and predictors which would permit the business and labor conditions of the future to be included

in a design-to acquisition cost. Better operations data gathering and cost modeling would permit the use of design to life cycle cost or cost of ownership targets. There is an impact on total acquisition and ownership costs as a by-product of designing to a unit recurring cost target. Simplicity is designed into the product, and simplicity is usually accompanied by reliability and maintainability benefits.

APPLICABILITY

Design to a cost is appropriate for use in low technology and low cost systems right up through the latest proven advances in technology and high cost systems. Design to a cost is inappropriate for use in a system intended to advance the state of the art or to seek out new technology because the cost of undefined or unknown elements can not be estimated with accuracy sufficient to design to a cost.

The AMST serves as the example of a system which will demonstrate already proven technology which uses the latest techniques and tools in manufacturing to produce a relatively complex system. But all of the technology and techniques are known, and while there is some uncertainty that it will all come together in a perfect and harmonious system the first time, there are no unknowns. Design to a cost requires that the design team be able to define, design, analyze and estimate the cost of each part in the overall system.

The inclusion of non-definitized subsystems or unproven performance requirements in system goals prevents the application of design to a cost as a reasonable cost control technique. An F-15 or a B-1 could not have been designed to a cost, but those subsystems or assemblies which were within the state of the art could have been designed to a cost. Complexity and high cost do not obviate design to a cost, as long as there is enough time to do the detail work, but undefined and unknown design factors by their very nature cannot be designed to a cost.

The effectiveness of design to a cost is related to the conviction of those using the concept. In directing design to a cost, cost must have priority among decision parameters. If a decision has been made to give cost priority, then the program must be supported as design to a cost at all levels in DoD and by contractors and suppliers. Design to a cost appears to be inappropriate for getting additional performance or growth potential in a weapon system. If an adequately performing system cannot be designed to an established cost target, then the program should be abandoned or reestablished with a different cost target. The failure of design to a cost to result in an adequate system raises the issue of the competence and commitment of the contractor. It also raises the issue of performance requirement and the established cost target.

It is concluded from this research that no serious problems have thus far been encountered in implementing

design to a cost after the target cost and system performance goals have been established.

RECOMMENDED AREAS FOR FURTHER STUDY

The effectiveness of design to a cost in weapon system procurement can not at this time be judged with finality. The concept appears to be working, but will the systems procured this way provide the required capability? That question is outside the scope of this study and outside the time frame of the programs studied. The conclusion of this study that no serious problems have been encountered causes one to wonder why this concept has not always been used. Is DoD getting something for nothing, for the first time, with this new, problem-free design to a cost? The answer to that question appears from this study to be affirmative with regard to implementing the concept in cases where its use has been directed.

The crux of the something for nothing issue lies in an evaluation of whether or not a weapon system should be procured under design to a cost. If DoD wishes to procure weapon system X, will design to a cost procure the same system cheaper? When DoD deploys system X which has been designed to a cost will it do the job? Basically, the issue is, Which required operational capability can be satisfied by a system designed to a cost?

An issue raised by the decision to design to a cost is, What cost? How should DoD go about assigning a system worth

or value to an operational capability? Where did the \$1.4 million target for the A-X or the \$5 million target for the AMST come from? On what basis and by what methods should DoD decide in system target costs? What should be the mechanism for quantifying performance without specifying design? Perhaps further study in this area would permit design to a cost to be more broadly applied.

Life cycle cost or total cost of ownership modeling could enhance cost reduction efforts by permitting the addition of more cost elements to design to a cost targets. Research in this area might help to decide how much in resources should be devoted to which cost elements.

It is recommended that further study be undertaken in the areas of design to a cost applicability, target cost establishment and expanding the categories of cost elements which can be used as design to a cost targets.

VIII. SUMMARY

During the past 10 years increasing pressures on the federal budget, and particularly on the DoD share of that budget, have forced tighter management of the resources used to acquire weapon systems. The 1971 publication of DoD 5000.1 established the design to a cost concept to be used to control costs in major weapon system acquisitions.

Whether or not design to a cost is a viable concept is at this time immaterial; the concept has been imposed on Defense contractors and the imposition of a new concept or procedure is usually accompanied by the emergence of problems related to the new concept.

The first task of this study was to define in an acceptable and operational manner just what design to a cost means. The next task was to examine some weapon system acquisition programs to determine what problems were being experienced in implementing the design to a cost concept. It was also hoped that an examination of problems experienced by some programs might prove to be preventable in future programs if some guidelines for future applications of design to a cost could be inferred from the data gathered.

Design to a cost is not a new system or a set of procedures set down in a rule book of the how-to variety. Steps to be taken and guides for those unfamiliar with the concept have been written, but rather than defining the concept they provide a systematic approach to operating with the

concept. Design to a cost is the process of designing against an established cost target, of making tradeoffs to get the most performance out of a design which is possible without exceeding the cost target. Cost enjoys a priority equal to any other design parameter.

The SCAD was chosen as the subject for study since it reportedly employed the design to a cost concept. The cost to implement design to a cost by negotiating contract changes with sole-source suppliers proved prohibitive, and the SCAD program could only implement a program of heightened cost awareness. The SCAD program was subsequently reduced to a study effort forcing this study to be conducted elsewhere.

The A-X SPO released the RFP for a competitive prototype phase with a design to a cost target set for a production aircraft at \$1.4 million in FY 70 dollars unit recurring fly-away cumulative average cost for 600 units. The RFP specified only performance goals, not requirements. The Fairchild-Republic design, subsequently designated the A-10, was selected the winner of the CPP, and a contract for a ten-aircraft full scale development was awarded. The aircraft is a low technology, low cost system with no risks accepted where alternative, proven methods can be used. The only problem of any significance to design to a cost was encountered early in the preliminary design phase when both company designers and subcontractors did not design with sufficient cost consciousness. Change was brought about in

this design subculture of the DoD procurement culture through training and increased managerial emphasis. The incentive of a six hundred aircraft buy was sufficient to motivate a company to pursue design to a cost efforts.

The AMST RFP for a prototype development was released with a design to a cost target priority not initially sufficiently well established to obtain the desired results. A Phase I Study contract award to Boeing and Douglas brought the cost target to higher priority, and Phase II go-ahead was given to each contractor to design, develop, fabricate, test and support two aircraft each to demonstrate new lift technology and define STOL operations. The design to a cost target was established as \$5 million in FY 72 dollars unit recurring flyaway cost at the three hundredth article for a production version.

The Douglas YC-15 is a four-engine jet transport using externally blown flaps to generate lift. The Douglas contract is for cost sharing with a government share of approximately \$86 million. The Boeing YC-14 has two engines mounted above the leading edge of a high wing and employs upper surface blowing lift technique. The Boeing contract is cost plus fixed fee with a maximum obligation to the government of approximately \$96 million.

The design to a cost problems associated with the AMST result primarily from confusion and uncertainty in communication requirements and also from the nature of the established

target cost There is evidence that the design subculture problem existed with the AMST contractors but was of smaller magnitude because of the commercial experience of both firms.

From data gathered in this study problems in implementing design to a cost were found in the areas of communication, culture, operation and applicability. No specific problems were encountered which might cast doubt on the value of the design to a cost concept selectively applied.

But the employment of the design to a cost concept does involve more than just making tradeoffs in the design phase. In choosing to buy under design to a cost the buyer gives up control over performance. The contractor must have the flexibility to accept degraded performance in order to reduce cost.

In either a sole-source or competitive environment the intent of the contractor to sell as many airplanes as he can is the major incentive toward effectively executing a design to a cost program. The buyer is dependent upon the motivation of the contractor to bring the best possible performance from the resources allocated. It would seem that for DoD or the Air Force to depend on that for a militarily adequate weapon system might be an unsatisfactory situation. Will the system do the job?

The problem of contracting to enforce the cost target also remains. If the contractor says that he can not meet the cost target there appears to be no contractual leverage available to enforce it. The design to a cost concept is inextricably related to the motivation and intent of the contractor.

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